THE INFLUENCE OF THE LOCAL VARIATION IN PHYSICO-CHEMICAL PROPERTIES OF COATED PAPER ON BACKTRAP MOTTLE

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Abstract: In multi-color offset printing, backtrap mottle (BTM) has been a serious concern for many coated papers. In the first part of our study, the point-to-point variation in the tack buildup on coated paper was found to correlate well with the backtrap mottle. Therefore, the local variation in the physico-chemical properties of coated paper affecting ink setting might be the key to backtrap mottle. In this part, two coated papers with much different degrees of backtrap mottle were examined physically and chemically using mercury porosimetry, stylus profilometer, environmental scanning electron microscope (ESEM), energy dispersive spectroscopy (EDS) and contact angle measurements. These two samples had identical coating composition and the same coat weight, but were dried under different conditions. The results obtained indicate that the sample with heavy backtrap mottle has larger regions of "closed" surface on the surface compared with the samples with little backtrap mottle. There is little difference in distribution of binder, wettability and roughness between two samples. It is concluded that the presence of the "closed" areas is the most important factor for backtrap mottle with coated paper in multi-color offset printing.

Introduction

Coated paper has a higher smoothness and a finer pore structure than uncoated paper. It is widely used in multi-color printing for magazines and advertisements. Coated paper has been the fastest growing paper grade. However, this does not mean that print quality problems are fewer and less

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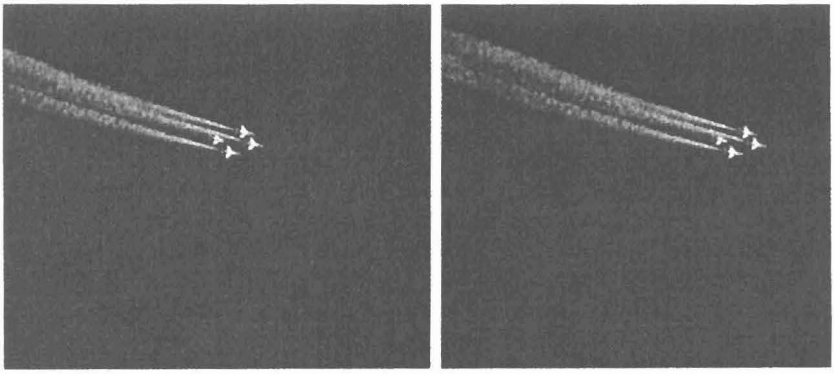
serious with a coated paper. One of the most serious and frequent problem is backtrap mottle (BTM). It is an undesirable unevenness in print density and is thought to be caused by non-uniform ink setting in adjacent area on coated paper in multi-color offset printing.

Many investigation into the cause of BTM have been conducted and reported by several authors (Isoard, 1983; Aschan, 1986; Lyne, 1986; Nelson, 1986; Nishioka, *et al* 1986; Arai, *et al,* 1988; Engstrom, *et al* 1987; Aspler and Lepoutre, 1991; Louman, 1991; Kumana, et al 1993; Gane, *et al*, 1994; Plowman Sandreuter, 1994; Engstrom, 1994; Miwata, H., *et al*, 1995). Many agree that the BTM is caused by an uneven distribution of binder at the coating surface, the result of binder migration from coating layer during the consolidation. It is believed that binder migration generates an increase in binder concentration at the coating surface, and generally ink in the area with higher binder concentration sets slower than the area with less binder migration. So the drying strategy which affects binder migration is considered to have a significant effect on the backtrap mottle of coated paper. On the other hand, the result reported by Gane (1989) suggested that binder migration does not cause BTM independently of surface roughness and coverage. So the mass distribution of the coating layer is considered as another important factor which affects BTM. Faster ink setting in lower coat weigh areas was found by Isoard (1983). A better correlation of ink density variations with coat weight variation than surface latex concentration variation was found by Inoue, *et al* (1992). A recent study by Kim, *et al* (1997) indicated that there were no significant difference in distribution of surface components, determined by XPS, between samples with good and poor BTM and suggested that the existence of some mottle-controlling parameter other than surface binder distribution. However, no direct evidence of changes in surface pore volume or pore size distribution which affects ink setting was reported in conjunction with both the binder migration and coat weight distribution. Systematic and direct studies are lacking. Recently, a novel method and device to quantitatively measure the tack buildup of offset ink and its local variation on coated paper at millimeter scales was developed in our laboratory (Xiang, *et al*,1998). A map of the rate of tack buildup on coated paper which is directly related to BTM can be obtained. It was found that the point-to-point variation in the initial rate of tack buildup correlated well with BTM rating of coated paper. The current understanding is that ink tack build on coated paper is caused by the evaporation of solvent into air and the penetration of the solvent phase with low molecular weight resins of ink to the paper. The microporosity and the surface chemistry of the coating are two controlling factors of ink tack build. Both of these can be greatly influenced by the binder system. So the local variation in the physico-chemical properties of coated paper affecting ink setting might be the key to backtrap mottle. Further understanding of the mechanism that causes the local tack variation on coated paper is desired.



Sample G *Sample A*

Figure 1 Prints of Sample G and Sample A with Six-Color Offset Press. A heavy backtrap Mottle can be seen on the Sample G.

In this work two coated papers had the identical base stock, identical coating composition and the same coat weight, but were dried under different condition and experienced different degrees of backtrap mottle in multi-color offset printing were examined physically and chemically using mercury porosimetry, stylus profilometer, environmental Scanning Electron Microscope (ESEM), energy dispersive spectroscopy (EDS) and contact angle measurements. The new Micro-Tackmeter was used. The purpose is to relate the variations in physico-chemical properties of coated paper to the local ink tack variation and in turn the backtrap mottle.

Experimental

Samples

Two coated papers experienced different degrees of backtrap mottle in multi-color offset printing were chosen. Figure 1 shows the prints of two samples obtained on six-color offset press. Sample G has much backtrap mottle and sample A has little. These coated papers all had identical coating composition, same base stock and same coat weight (23.0g/m^2), but were dried under different conditions. They experienced different degrees of backtrap mottle in six-color offset printing. Table 1 lists their basic properties, coefficient of variation in the initial rate of tack buildup and the subjective rating by printing experts. The measurement of coefficient of variation in the initial rate (b_2) of tack buildup was conducted according to our method reported before (Xiang, *et al*, 1998) and will be briefly described below. The subjective rating was obtained with pairs comparison and ranking method through evaluation by printing experts. The lower the rating number is, less serious the backtrap mottle is (1=excellent; 5=bad).

Table 1 Basic Properties of Two Samples, Their Coefficient of Variation in The Initial Rate of Tack Buildup and The Subjective Rating of Backtrap Mottle

Sample	Bright -ness, %	Opacity , %	PPS-10kg-soft, μm	75° Paper Gloss, %	75° HS Ink Gloss, %	Coeff. of Var. in b_2	BTM Expert Rating
A	78.6	98.9	1.32	62.6	85.8	0.286	1.5
G	79.4	98.8	1.30	63.2	86.0	0.535	5

Measurement of Local Variation of Ink Tack

The method and device has been described by Xiang, et al (1998) in detail. Figure 2 is a schematic of the device. The Micro-Tackmeter contacts a metal probe to an ink film on Mylar to apply ink to the probe. The inked probe then contacts a substrate and measures the force to pull the probe off from the surface. The splitting force between inked probe and inked paper is proportional to the deflection of the leaf spring which is measured by the LVDT (Linear Variable Differential Transformer). A computer controls the motor and records the LVDT output. Before running the Micro-Tackmeter, a certain amount of ink ($16.50 g/m^2$) is applied to a plastic film (Mylar) using IGT AIC2-5 printability tester and the Westvaco rod applicator. The test paper and the inked Mylar film are attached to a smooth metal block using double-sided tape. The Micro-Tackmeter is operated. The probe touches the inked Mylar film to apply ink to the probe. The inked probe touches the test paper many times at a single point to measure the change of ink tack with time. A graph of the tack forces versus elapsed time is generated and is used to interpret the ink/paper interaction. In this way, the time interval between ink contacting paper and the first measuring point is about 5 seconds, which is much less than the time interval between direct printing of the paper and the first measuring point. Both printing and micro-tack measurement were carried out at 23°C and 50% relative humidity. In multi-color offset printing, cyan produces the most objectionable backtrap mottle because the human eye is very sensitive to a slight variation in density of this color. So in this paper, a process cyan ink was used; the one used is a typical quick-set offset ink (Capiplus III Process Cyan, Flint Ink Inc.).

Energy Dispersive Spectroscopy (EDS)

A energy dispersive spectroscopy (EDS) by Noran Instruments was used to determine the chemical compositions on paper surface. Both chemical composition and mico-image of measuring area can be obtained. X-ray maps and linescans can be acquired simultaneously.

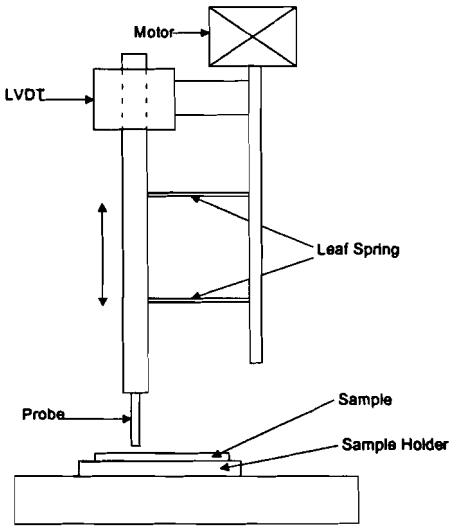


Figure 2 Schematic of the device. The LVDT and Motor are connected to a computer for motor control and data acquisition. The LVDT records the relative position of the probe to the motor assembly.

Measurement of Pore Volume and Pore Size Distribution

PoreSizer 9320 mercury porosimeter by Micomeritics was used to determine the porosity, pore size distribution of two samples. This device has a pressurization systems generating pressures from 0 to 30,000 psia with an accuracy of ±0.1% psia of full scale. Pore sizes from 0.006 to 360 μm diameter can be detected.

Measurement of Surface Roughness

Surface roughness was measured using a Alpha-Step 200 stylus profilometer by Tencor Instruments. All measurements for two samples were conducted with 5 micrometer stylus and 8.0 mg tracking force (corresponding to a 10.2 kgf/cm^2 stylus pressure). The arithmetic average surface roughness (Ra) is determined using the graphical-centerline method.

Surface Examination in the Environmental Scanning Electron Microscope (ESEM)

Type ElectroScan E3 environmental scanning electron microscope (ESEM) was used to examine the surface pore structure.

Measurement of Contact Angle

A video system was used for measuring the contact angle. The profile of a liquid drop resting on the surface at different time was recorded. The contact angle is obtained by measuring the dimensions of a liquid drop image captured on computer. A drop with a volume of 5 μl and HPLC grade water were used for this study.

Results and Discussion

Variation in Chemical Composition

It is well known that the level of binder in a coating can significantly affect the ink setting rate. Recently binder chemistry to control the solvent diffusion into the binder has also been found to be an important factor in affecting ink setting on the coated paper (Kelly *et al* 1971;Van Gilder and Purfeerst 1994; Aspler, *et al* 1997). So it is expected that a different binder distribution should be found on two samples with different levels of backtrap mottle. A side-by-side measurement was done to determine the variation in chemical composition. 500 magnification is used in the ESEM. The center distance between two adjacent measuring spot is 500 μm and 16 points are measured for each sample. Five elements carbon (C), oxygen (O), aluminium (Al), silicon (Si) and calcium (Ca) in the coating composition were detected. Table 1 shows the EDS results from side-by-side measurement for two samples with very different degrees of backtrap mottle. As shown in table 1, there was no significant difference in the average of the chemical composition between two samples, but only a lightly larger variation in chemical composition is found for sample G with heavy backtrap mottle compared with sample A with little backtrap mottle. This result is similar to the result obtained by Kim, *et al* (1997) who used XPS. So it seems that backtrap mottle on sample G is not mainly caused by the non-uniform distribution of chemical composition, and in turn, binder on coated paper surface. Other factors might play a more important role in causing backtrap mottle.

Table 1 Energy Dispersive Spectroscopy (EDS) Results

Elements		C	O	Al	Si	Ca	(Al+Si)/C
A	Average	10.2	46.1	14.1	14.8	14.6	2.8
	Coeff. of Var., %	2.2	0.6	2.5	1.6	1.6	3.3
G	Average	10.3	45.7	14.0	14.6	14.5	2.8
	Coeff. of Var., %	4.2	0.7	4.0	3.2	1.6	4.2

Variation in Contact Angle with Water and the Surface Roughness

Both the local variation in wettability and the surface roughness are believed to lead to a disturbance in the ink transfer of multi-color offset printing. When ink is transferred to the paper surface in printing nip, both the emulsified fountain solution in the ink and the solvent of the ink wet the paper surface. The contact angle of the surface with water is a measure of wettability of the paper surface. It is known that when a liquid drop is placed in contact with a flat substrate, the drop spreads spontaneously toward equilibrium and the contact angle relaxes from its initial maximum to its equilibrium angle. Table 2 shows the results of contact angle of two samples with water at time 0, 5 and 10 seconds respectively after water drop contacts the paper surface. Contact angle at time 0 is obtained by extrapolating the curve of contact angle against the time. It is shown that there is not much difference in the variation in initial contact angle (at time=0) between the two very different samples, but at time=10 seconds after the drop contacts the surface the sample G with heavy backtrap mottle has a larger coefficient of variation in contact angle than the sample A. This means that the sample G has a more non-uniform spreading of the drop caused by the capillary force of the surface coating. It is also noted in table 2 that the sample G has a smaller contact angle than the sample A at all time scales. The reason for this is still not clear.

Table 3 shows the results of surface roughness (Ra) from stylus profilometer at two different scanning length and the Parker Print Surf roughness. The Ra is is the average of 10 scannings on each sample. It can be seen that there is not significant difference in PPS roughness (PPS-10kg) and in stylus profilometer roughness (Ra) at the short scanning length (2 mm). At the longer scanning length (10mm), the sample G has a larger Ra than the sample A. This difference probably is caused by a larger waviness of the sample G at longer scanning length. This waviness could disappear in the printing nip.

Table 2 Variation in Water Contact Angle of Two Samples

Time, s	0		5		10	
	Average	Coeff. Var.	Average	Coeff. Var.	Average	Coeff. Var.
A	79.2	0.05	74.3	0.04	73.6	0.04
G	73.6	0.05	70.0	0.05	66.6	0.11

The Micro-Pore Structure of the Coating

The paper surface with pigmented coatings is porous with a pore diameter range from 0.05 to 0.5 μm. In principle, these pores should act as a filter for the ink

Table 3 Stylus Profilometer Surface Roughness (Ra, μm) and the PPS-10kg

Scanning Length, mm	10	2	PPS-10kg, μm
Sample A	1.933	1.140	1.32
Sample G	2.463	1.180	1.30

solvents, so that the pigment and resin they can remain on the top of the paper to have a high print density. At the same time, the solvent in the ink as a carrier and the emulsified water in the ink in offset printing should be absorbed by the pores fast enough to accept another ink film on the top of the first. The contribution of the pore structure to ink setting on coated paper has been reviewed by Aspler and Lepoutre (1991). The pore structure of paper coatings is thought to be the most important factor in regard to the ink setting on coated paper in printing. Non-uniform ink setting on coated paper causes a non-uniform tack development. So the local variation in pore structure might be the most important factor causing backtrap mottle in multi-color offset printing.

However, there is not much difference in the pore distribution for our two samples for Mercury Porosimetry, as shown in Figure 3. As described before these two samples are coated on both sides. The mercury porosimeter measures a larger area of the sample. So the result obtained by mercury tends to integrate a large area. The local variation in pore structure is not differentiated.

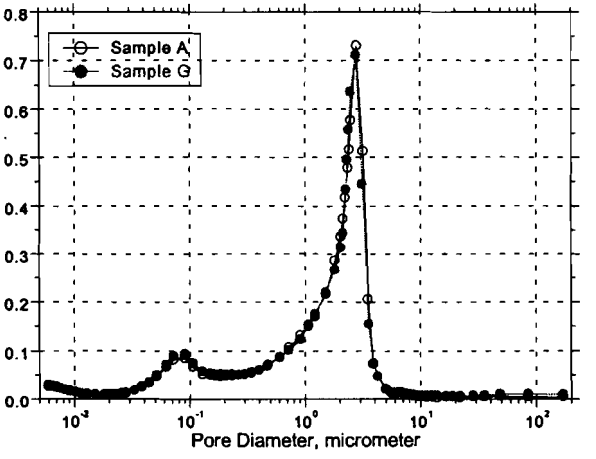


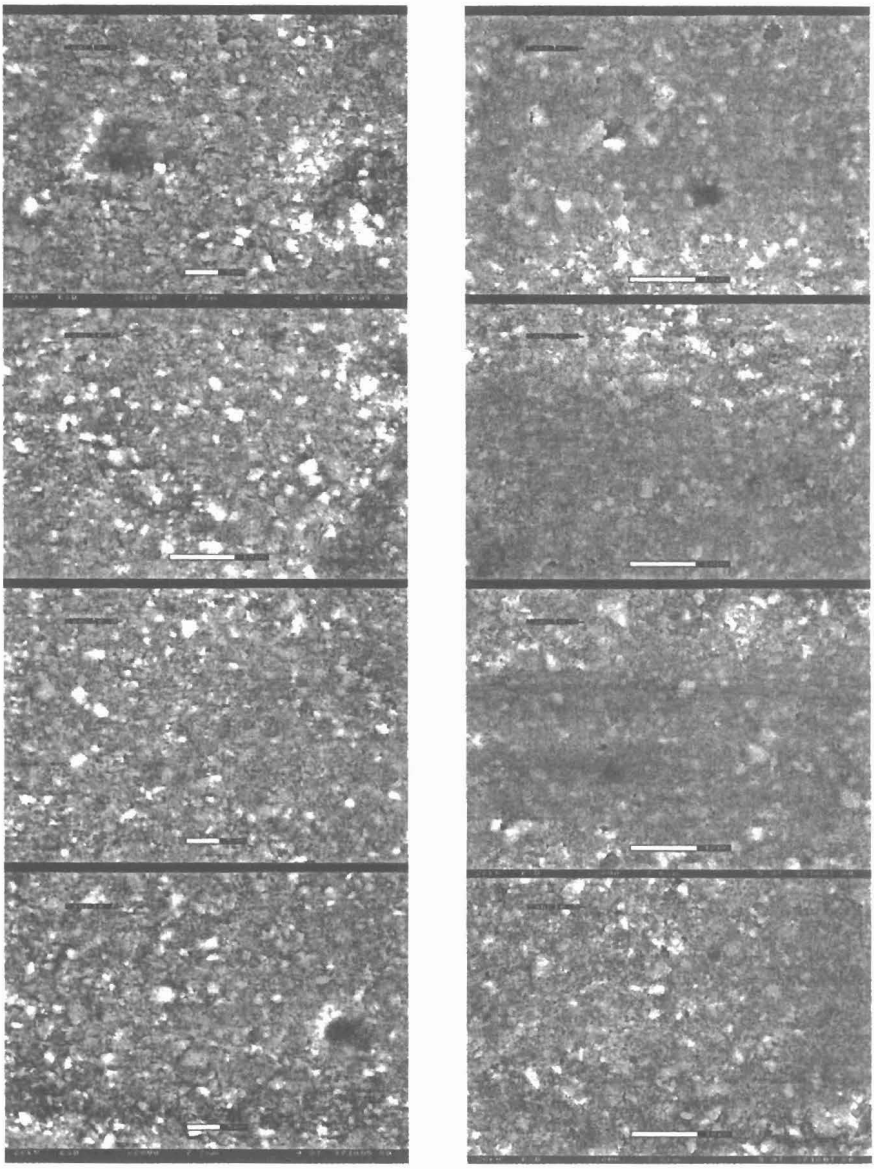
Figure 3 Pore distribution of sample A and Sample G

In order to view the local variation in pore structure, a side-by-side examination of the surface of the two samples under the Environmental Scanning Electron Microscope (ESEM) was done. Figure 4 shows part of images we did under the magnification of 2,000 for each sample. It can be seen that the sample G with heavy backtrap mottle has more "closed" areas on the surface than the sample A with little backtrap mottle. A closer view of both porous areas and "closed" areas is shown in Figure 5. Figure 6 shows both porous areas and "closed" areas of sample G under lower magnification. The "closed" areas look darker and the porous areas look lighter. However, the size of the "closed" areas is much smaller than the size of the backtrap mottle pattern, ink setting would be much slower in these areas than that in the porous areas because of less capillary fore for absorbing the solvent and emulsified water inside the ink. After backtraping in the proceeding printing units, less ink would remain on the surface of these areas. Several of these kind of "closed" areas would produce the backtrap mottle we can see with our eyes.

To examine if there is any difference in binder content between the porous area and the "closed" area, EDS was done in two areas under 1,000 magnification. Elements C, O, Al, Si, Ca related to coating composition were detected. However no significant difference in chemical composition was found between the porous areas and the "closed" areas as shown in table 4. Each value in table 4 is the average of 5 individual measurements. This result indicates that the non-uniform pore structure is not caused by the non-uniform distribution of coating binder on the surface. Although the real reason these "closed" areas are produced is not clear, non-uniform distribution of moisture in coating caused by severe drying condition before calendering might be the most important factor to be considered.

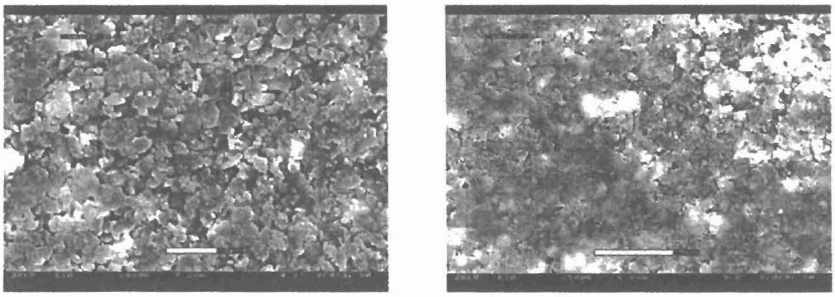
Table 4 EDS Results of the Porous Area and the "Closed" Area

Elements	C	O	Al	Si	Ca	(Al+Si)/C
"Closed" Area	10.20	44.54	14.42	15.16	14.83	2.90
Porous Area	10.27	44.93	14.34	15.03	14.86	2.86



(a) (b)

Figure 4 Part of Side-by-Side ESEM Pictures of Sample A (a) and Sample G (b).



(a) (b)

Figure 5 ESEM Pictures of Porous Area (a) and "Closed" Area under Higher Magnification

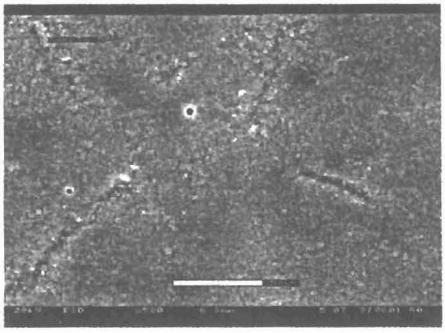


Figure 6 ESEM Picture of Porous Area (lighter) and "Closed" Area (darker) of the sample G under Lower Magnification

Conclusion

Two coated papers with identical coating composition, and dried under different conditions, experienced much different backtrap mottle patterns when printed in multi-color offset printing were examined physically and chemically. No significant differences in the non-uniform distribution of chemical composition or wettability was found between the two different samples. The sample with heavy backtrap mottle did have more "closed" areas than the sample with little backtrap mottle when viewed under the ESEM. Based on the results obtained, it is concluded that the backtrap mottle is mainly associated with the non-uniform distribution of micro-pore of the coating, the presence of the "closed" areas. Further investigation is needed to quantify the contribution of pore structure to ink tack development.

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